Furrow Compaction for Controlling Excessive Irrigation Water Intake

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ABSTRACT

IRRIGATION of moderately permeable soils by the graded furrow method can result in excessive water intake and major losses to profile drainage. Irrigation water management practices that have been developed to limit excessive water intake in graded furrow systems are wide spacing, wheel compaction, and smoothing of irrigated furrows. A field study was conducted on Olton clay loam (fine, mixed thermic family of Aridic Paleustolls) to evaluate effects of increasing irrigated furrow spacing from 0.75 to 1.5 m and furrow compaction on irrigation water intake, evapotranspiration, estimated profile drainage losses, and corn yields. Wide spacing of furrows had very little effect, while wheel compaction reduced the average water intake during seasonal irrigation from 123 to 82 mm and estimated profile drainage losses from 29.4 to 9.1% of water applied. Tractor-wheel compaction from multiple field operations increased average dry soil bulk densities from 1.26 to 1.62 Mg/m^3. Irrigated furrows were compacted as a separate tractor pass prior to the preplant irrigation, and effects remained through the growing season. The reduced water intake with furrow compaction did not affect corn grain yields. Alternating compacted and noncompacted furrows permits flexibility in irrigating for a range in water intake, depending on water use rates and profile soil water depletion. Irrigation of compacted furrows permits the use of a fixed pumping rate to irrigate a larger area by reducing profile drainage and increasing field application efficiency.

INTRODUCTION

Graded furrow irrigation is practiced on about two-thirds of the irrigated area in the Southern High Plains. It is practiced about equally on slowly permeable clays and clay loams and on moderately permeable soils with textures ranging from clay loam to fine sandy loam. Studies of water storage following irrigation (Musick et al., 1971; Musick et al., 1973) and deep coring of irrigated fields (Aronovici, 1971; Aronovici and Schneider, 1972) indicate that water losses to profile drainage are low to negligible on the slowly permeable clays, such as the Pullman clay loam (fine, mixed, thermic family of Torrertic Paleustolls) at Bushland, Texas. The major water loss from furrow irrigation on the slowly permeable soils results from tailwater runoff.

On the moderately permeable soils, however, water loss results from both tailwater runoff and profile drainage below the root zone. These medium-textured soils have lower water storage capacities and higher hydraulic conductivities than the slowly permeable clays. Uniform profiles of medium-textured soils can drain at continuously declining rates for several days following irrigation. Willardson and Pope (1963) presented drainage curves for different soils and surface covers that showed accumulated profile drainage of 50 to 100 mm over a 2-wk period following irrigation.

Tailwater recovery systems are widely used in the Southern High Plains for reuse of runoff. Since profile drainage losses are not visually evident to farmers and have seldom been measured in this region, practices to reduce these losses have been slow in developing. A common practice to limit the quantity of water intake in graded furrows has been to irrigate widely spaced furrows or alternate furrows in either normal row cropping or skip-row systems (Musick and Dusek, 1974; Musick and Dusek, 1982). In normal irrigated row cropping, use of 0.75-m row spacing and irrigation of 1.5-m furrow spacing is increasing. The use of wider spaced furrows, such as 2.0 m, resulted in inadequate wetting of the lower part of the field on a slowly permeable clay loam (Musick and Dusek, 1974).

Water intake quantity and potential loss to profile drainage can be further reduced on moderately permeable soils by using tractor wheel traffic for compaction of wide-spaced irrigated furrows. Furrow compaction for controlling infiltration was evaluated in studies by Khalid and Smith (1978), Akram and Kemper (1979), Elliott et al. (1983), and was discussed in a review by Kemper et al. (1982). The third author developed an irrigation system that consists of alternating 0.75-m spaced furrows that have no wheel traffic, designated as SOFT furrows, and adjacent furrows that were compacted by tractor wheels, designated as HARD furrows. If increased water intake is needed, the 1.5-m spaced SOFT furrows are irrigated. The normal practice, however, is to irrigate the 1.5-m spaced HARD furrows.

This paper reports the results of testing the irrigation of SOFT and HARD furrow treatments for corn production compared with a conventional control treatment of every-furrow (EF) irrigation. The EF Treatment had alternating pairs of HARD and SOFT furrows. We evaluated soil bulk densities below the soil surface in irrigated furrows, irrigation water application, intake, surface runoff, soil water storage, estimated profile drainage, evapotranspiration (ET), and corn yields.

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PROCEDURE

The study was conducted on a field of Olton clay loam (fine, mixed thermic family of Aridic Paleustolls) in Parmer County, Texas, in 1982. The Olton soil has a reddish-brown, neutral, clay loam surface layer about 0.2 m thick. The subsoil is blocky clay loam to a depth of 1.2 m. It is reddish brown in the upper part and yellowish red below 0.8 m. From 1.2 to 1.8 m, it is pink clay loam containing about 50% by volume calcium carbonate. Below 1.8 m, it is reddish-yellow clay loam containing about 25% calcium carbonate. The average available water capacity is 16% by volume for an approximate available water capacity of 224 mm to 1.4-m profile depth to caliche.

The field was 400 m long with a furrow grade of 0.25%. Irrigation treatments consisted of (a) water application to EF (control treatment), 0.75-m irrigated furrow spacing; (b) irrigation of nonwheel track SOFT furrows, 1.5-m spacing; and (c) irrigation of wheel track HARD furrows, 1.5-m spacing. Hard furrows were compacted as a separate tractor pass prior to preplant irrigation. Each treatment consisted of a field strip of forty 0.75-m corn rows and irrigation furrows that were sampled for soil water and grain yields on four 100-m length of run blocks. Block-treatment interactions were used in statistical analysis of variance of treatment effects.

Irrigation was applied through gated pipe, with the application measured by a propeller meter. Tailwater runoff was collected in a ditch and measured with a long-throated flume (250-mm throat width) equipped with a water stage recorder (Replogle and Clemmens, 1981). Furrow application rates averaged 0.95 L/s for the EF control treatment and 1.9 L/s for the SOFT and HARD furrow treatments.

The preplant irrigation, which was not measured, was uniformly applied to HARD furrows on all plots. Differential irrigation treatments were started with the first seasonal irrigation. Four seasonal irrigations were applied during the dates June 28-July 1, July 17-18, Aug. 2-3, and Aug. 23-24. Most irrigations were about 12-hr sets, with some of longer duration. The Aug. 23-24 irrigation to the HARD furrows was applied at an average flow rate of 0.95 L/s as a result of irrigating from a tailwater pit with limited water in storage during the irrigation set.

Two 60 deg, V-notch furrow flumes equipped with water stage recorders were placed in individual furrows at the lower end. Flume stage recorder charts were used to determine the field length water advance time.

Irrigated corn was grown on the field the previous year. During fall to early winter, stalks were shredded and the field was disked and chiseled twice. Liquid fertilizer was applied at the rate of 17 kg N, 50 kg P, 17 kg K, and 17 kg sulfur per ha. Operations during late winter to early spring were disking, application of 230 kg/ha N as NH_3, floating, listing for 1.5-m furrow spacing, and tractor wheel compaction of all the 1.5-m spaced furrows (International 6388*, 4-wheel drive row crop). Preplant irrigation was applied in March followed by cultivation before planting. Corn 'NK PX72' was planted for a measured plant density of 5.8 per m^2. The corn was cultivated three times prior to the first seasonal irrigation and the SOFT furrows were formed during these cultivations. Cultural operations were with 8-row equipment.

Soil water was sampled by the neutron method in two access tubes placed in the beds in each 100-m length of run segment (8 tubes per treatment). Soil water data were taken after emergence, immediately before and one to three days after irrigation and at maturity. Sampling increments were by 0.2 m to the 1.2 m depth and by 0.3 m to the 3.0 m depth. Profile sampling of a nearby field cropped to corn indicated good root penetration to caliche (about 50% calcium carbonate), but indicated no significant penetration into the caliche. The abrupt lower limit to rooting defined a soil volume for calculating evapotranspiration (ET) by a water balance method. Soil water depletion to 1.4 m was considered as ET by the crop and depletion below 1.4 m, following irrigation, as estimates of profile drainage.

Soil cores (50 mm diameter by 75 mm deep after removal of the surface 25 mm of loose soil) were collected for furrow bulk densities on four dates (before planting, June 24, July 14, and July 29). Eighteen cores were collected on each date to determine densities of tractor wheel furrows (multiple passes), implement gage wheel furrows that had the one initial tractor wheel pass, and nonwheel track furrows. The use of 8-row equipment resulted in paired 1.5-m spaced furrows being traversed by tractor and implement wheels for all operations after preplant irrigation.

A 5-m^2 sample was hand harvested on Sept. 20 for grain yield from each of four rows at each segment site, for a total of 16 yield samples per treatment. Ear samples were oven dried (70 °C) to constant weight, shelled, weighed, and yields adjusted to 15.5% moisture, wet basis. An adjacent 8-row combine strip was harvested on Oct. 6.

RESULTS AND DISCUSSION

The 1982 season was favorable for corn production. Seasonal rainfall (205 mm) was near normal, and air temperatures were predominantly moderate for the area. June rainfall permitted omitting an early season irrigation (normally applied about mid-June) which reduced the number of seasonal irrigations needed to four. The first irrigation was applied about 10 days before pollination, the second at the initiation of grain filling, and the last two during the grain filling period.

Water Applied, Tailwater Runoff, and Net Intake

Data on water application, tailwater runoff, and net intake are presented in Table 1. The average water intake by the SOFT furrows averaged 123 mm per irrigation or 95% of the 130-mm average intake on the EF control area. The HARD furrow treatment averaged 82-mm intake per irrigation or 63% of the EF control and 67% of the SOFT furrow treatment.

Tailwater runoff for the four seasonal irrigations averaged 14.5% of the water applied for the EF control treatment, 13.4% for the SOFT furrows, and 26.7% for the HARD furrow treatment. The tailwater was utilized through a return system to supplement the water supply.

*Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agriculture.

TABLE 1.
IRRIGATION WATER APPLIED, TAILWATER RUNOFF, AND NET INTAKE FOR THE 4 SEASONAL IRRIGATIONS.

Irrigation dates		Treatments		
		EF control, mm	SOFT, mm	HARD, mm
June 28-July 1	Applied	131	144	97
	Runoff	9	35	22
	Intake	122	109	75
July 17-18	Applied	135	138	138
	Runoff	24	18	60
	Intake	111	120	78
Aug. 2-3	Applied	200*	127	142
	Runoff	40	7	25
	Intake	160	120	117
Aug. 23-24	Applied	141	158	72†
	Runoff	17	16	15
	Intake	124	142	57
Average	Applied	152	142	112
	Runoff	22	19	30
	Intake	130	123	82

*Extended application due to pump cutoff during irrigation and restart to complete the irrigation.
†Furrow flow rate reduced by one-half.

Soil Bulk Densities and Water Advance Times

Dry soil bulk densities at a depth of 25 to 100 mm below irrigation furrows are presented in Table 2. Bulk densities averaged 1.17 Mg/m³ for SOFT furrows before irrigation. Following irrigation, densities were in the 1.2 to 1.3 Mg/m³ range and did not significantly change during the remainder of the season. The HARD furrow treatment had alternating pairs of furrows that experienced multiple passes of tractor wheels or one pass of tractor wheels for compaction preceding the preplant irrigation and multiple passes of implement gage wheels. Furrows were cultivated after the preplant irrigation. The implement wheels recompacted the soil at the 25 to 100 mm depth to average bulk densities of 1.46 Mg/m³ compared with 1.62 for the tractor wheels.

Water advance time to the end of the field averaged 5.0 h for furrows that had multiple tractor wheel passes and 5.7 h for furrows that had one tractor wheel pass and multiple passes of implement wheels. The similarity of advance time indicates that after initial compaction of all Hard furrows, subsequent passes by tractor or implement wheels had no differential effect on water intake. Advance time for SOFT furrows averaged 13.0 h (Table 3). On the control area that had alternating HARD and SOFT furrows, water advance time for HARD furrows averaged about one-half of the time for SOFT furrows, except during the first seasonal irrigation when advance time for HARD furrows was much faster. Wheel compaction caused very short advance times for the first two irrigations of the HARD furrow treatment. The effect was less pronounced later in the season with deeper rooting and greater profile water depletion before irrigation.

TABLE 3. IRRIGATION ADVANCE TIME TO END OF FIELD FOR EF CONTROL, SOFT, AND HARD FURROW TREATMENTS.

Irrigation dates	Treatments			
	EF control, h		SOFT, h	HARD, h
	SOFT	HARD		
June 28-July 1	10.6	1.5	14.0	1.7
July 17-18	11.6	6.3	13.2	2.7
August 2-3	7.1	2.3	13.6	8.8
August 23-24	12.0	5.2	11.2	9.5*
Mean	10.3	3.8	13.0	5.7

*Furrow flow rate reduced by one-half.

Seasonal Evapotranspiration (ET)

The ET rates calculated from soil water depletion to 1.4 m depth are presented in Fig. 1. Seasonal values for EF, SOFT, and HARD furrow treatments, respectively, were 818, 775, and 701 mm. Rates did not differ appreciably between treatments except for a significantly lower rate for the HARD furrows following the third

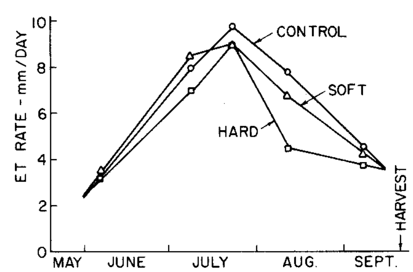

Fig. 1—Seasonal evapotranspiration rates of EF control, SOFT, and HARD furrow treatments.

TABLE 2. SOIL BULK DENSITIES (Mg/m³) MEASURED IN IRRIGATION FURROWS ON 4 DATES FOR TRACTOR WHEEL (HARD), IMPLEMENT GAGE WHEEL, AND NONWHEEL (SOFT) FURROWS.

Dates	EF control		HARD		SOFT
	HARD	SOFT	Tractor wheel*	Implement wheel†	
Before planting	1.60	1.17‡	1.63	1.44	1.16‡
June 24	1.59	1.27	1.66	1.48	1.27
July 14	1.62	1.31	1.60	1.46	1.25
July 29	1.65	1.27	1.60	1.46	1.28
Mean	1.62 a§	1.26 c	1.62 a	1.46 b	1.24 c

*Multiple passes.
†One initial tractor wheel pass and multiple implement wheel passes.
‡Furrow zone before forming the furrows.
§Mean values followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test).

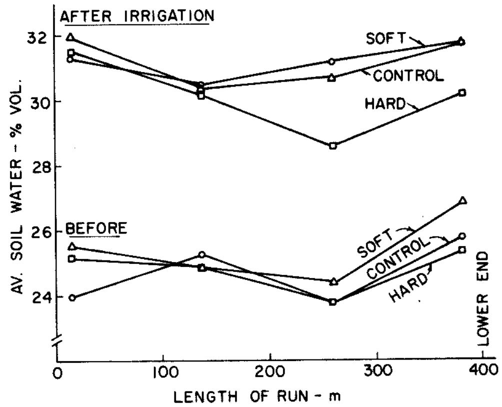

Fig. 2—Average seasonal soil water storage to 1.4 m depth before and after irrigation by length of run sites for the three furrow irrigation treatments.

irrigation. This reduced ET was associated with reduced mid- to late-season profile wetting of the lower half of the field as indicated by soil water contents following irrigation. This effect is illustrated by average soil water data plotted by "down the field" sampling sites in Fig. 2. The effect was visually evident by a few days accelerated senescence during the grain dry-down period.

Estimated Profile Drainage

Following the four seasonal irrigations, drainage estimates for the sampling intervals totaled 152, 137, and 33 mm for the EF, SOFT, and HARD furrow treatments, respectively. When the average rates were extended by linear extrapolation back from the sampling date to the day of irrigation, seasonal drainage estimates were 188, 152, and 46 mm for the three treatments, respectively. Average soil water contents before and after seasonal irrigations are presented in Fig. 3.

The magnitude of the estimated differences reflects significant treatment effects, particularly of wheel traffic compaction in HARD furrows. Estimated drainage below the 1.4 m depth averaged 30.8, 29.4, and 9.1% of water applied to the EF, SOFT, and HARD furrow treatments, respectively. Profile drainage losses for the EF and SOFT furrow treatments were similar, and losses for the HARD furrow treatment were greatly reduced. The results indicate that wheel traffic compaction of wide-spaced irrigated furrows can greatly reduce losses to profile drainage by reducing excessive water intake during irrigation of a moderately permeable soil. The results apply to profile conditions of limited rooting depth to caliche and to the common management practice of allowing about one-half of the available water in the profile to be depleted before irrigating corn. The reduction in estimated profile drainage corresponds to a similar reduction in seasonal water intake during irrigations.

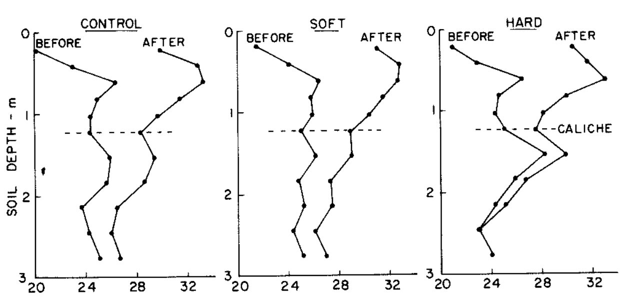

Fig. 3—Average seasonal soil water before and after irrigation by depth for the three furrow irrigation treatments.

Field Application Efficiency

Field application efficiency is defined as the percentage of applied water retained in the profile root zone. The two system losses are tailwater runoff and profile drainage. Although both are considered as losses to the field being irrigated, tailwater is partially recoverable and profile drainage may eventually contribute to groundwater recharge.

Considering both tailwater runoff and estimated profile drainage as losses, field application efficiency averaged 54.5, 58.5, and 63.7% for the EF, SOFT, and HARD furrow treatments, respectively. If the water supply had been used to irrigate a larger area for the HARD furrow treatment with a reduction in tailwater runoff to about the 10% range, field application efficiency would have been increased to about 80%, with about half the loss being tailwater runoff and half being profile drainage. However, irrigation of the larger area for a higher application efficiency and reduced tailwater runoff may increase soil water deficits on the lower part of the field and thus reduce corn yields. Yields of drought tolerant crops would be less affected by the lower soil water deficits.

Where conventional irrigation is practiced on soils having similar intake characteristics and fertilized at moderate nitrogen rates, some farmers have noted symptoms of N deficiency on the upper part of the fields (personal communications). An additional value of the HARD-furrow practice is reducing the potential for nitrate leaching below the crop root zone.

Grain Yields

Grain yields by hand-harvested length of run blocks and by combine harvest are shown in Table 4. Yields were similar among treatments and differed little by length of run. The reduction in ET by the HARD-furrow treatment is believed to be associated with favorable rainfall distribution and reduced yield sensitivity to water deficits. The few days accelerated senescence reduced ET rates approaching and continuing past physiological maturity, and the water deficits approaching physiological maturity probably enhanced translocation of previously stored assimilate to filling grain (Boyer and McPherson, 1975). The corn was grown under high

TABLE 4.
GRAIN YIELDS (Mg/ha) BY LENGTH OF RUN BLOCKS FOR THE FURROW IRRIGATION TREATMENTS.

Length of run blocks, m	Treatments		
	EF control	SOFT	HARD
Hand harvested:			
0-100	13.31	12.64	12.84
100-200	12.59	13.80	13.80
200-300	11.88	12.05	12.95
300-400	14.00	13.00	13.73
Mean	12.95 a*	13.08 a	13.34 a
Combine harvested:	11.98	12.51	12.49

*Mean values followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test).

fertility, and no nutrient deficiencies were noted during the season. Since the wheel-traffic compaction of irrigated furrows had no effect on yields, the practice increased the return per unit of net water intake.

Irrigation Management—Discussion

Irrigation water requirements for crops in the Southern High Plains vary with seasonal rainfall and the evaporative demand of the climate. Higher water use rates associated with prevailing hot, dry weather can appreciably increase irrigation water requirements. Having alternating SOFT and HARD furrows permits flexibility in managing irrigation water intake to meet evaporative demand conditions and the extent of soil-water depletion before irrigation. Where adequate water supplies are available during periods of high evaporative demand, irrigation of SOFT furrows can provide a more adequate supply for high yields.

During the early vegetative period, the depth of soil-water depletion is limited and roots extend into moist soil. Normally, smaller irrigations early in the season can replenish profile soil water, and irrigation of HARD furrows provides adequate water intake. "Getting behind" with irrigation is more likely to occur later in the season as deficits accumulate. Where adequate water supplies are available, an irrigation of SOFT furrows can be a management practice to "catch up" during the pollination and early grain filling periods. Stone et al. (1979, 1982) studied the effect of wide-spaced furrows for conservation of irrigation water. In their studies, they recognized the need to irrigate every furrow (conventional spacing) later in the season to provide adequate water requirements needed under prevailing climatic conditions of high evaporative demand.

In our study, pronounced differences in water advance rates occurred between the alternating HARD and SOFT furrows in EF irrigation. When irrigation of HARD furrows was combined with SOFT furrows, total water intake per unit land area was only slightly less than irrigation of the wide-spaced SOFT furrows only. Although irrigation of wide-spaced or alternate furrows irrigation reduced irrigation water intake in other studies (Allen and Musick, 1972; Fischbach and Mulliner, 1974; Musick and Dusek, 1974; Stone et al., 1979, 1982), our study suggests that wheel compaction of the wide-spaced irrigated furrows can be used to provide more specific control of excessive water intake.

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